Topics

- Description
- Capabilities
- **Methods**

Linear Interference Excision Methods

- Previous section has focused on linear interference excision capabilities — it remains to discuss algorithms that can achieve this capability in practice
- Linear algorithms can be divided into two broad (nonexclusive) classes of techniques:
  - Channel-directed or calibrated methods
    - » Combiner weights developed based on known or estimated propagation channel
    - » Includes parametric methods based on DF of the SOI or SNOI's (DF-aided copy methods), and nonparametric methods based on measurement and feedback of channel state information (CSI) to the receiver
  - Data-directed or uncalibrated methods
    - » Combiner weights based on known/estimated content or structure of the transmitted SOI
    - » Channel estimation/parameterization typically not needed
    - » Includes both nonblind and blind methods
- Both classes include cooperative methods in which the SOI emitter aids the interference excision process
  - Provision of emitter locations to aid parametric channel-directed methods
  - Exploitable SOI pilots or structure
- Choice of algorithms further influenced by characteristics of the environment and application
  - Strong SNOI's emphasize robust methods (e.g., voltage domain)
  - Highly dynamic SNOI's or SOI's (e.g., VoIP) emphasize rapidly converging methods

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Comparison of General Methods

Method	Description/Example	Advantages	Limitations
CSI-based nonparameterized channel-directed)	Measures channel-state at Tx, feeds back to Rx on side channel. Requires measurement <u>and</u> provision (feedback) of CSI to receiver	Easiest approach for receiver Can track arbitrary (slowly varying) channels	Requires feedback path (cost, latency, vulnerability) Hypersensitive in strong interference Fails in strong interference
Model based (parameterized channel directed)	Develops channel state from stored channel models or cal data Requires estimation or provision of emitter parameters (e.g., geo/DOA)	Potentially fastest adaptation if parameters available/observable Geo-observables typically provided as part of algorithm	Requires parameters (feedback path, loading limits) Hypersensitive in strong interference Very sensitive to parameter error, cal/modeling error
Pilot-based (nonblind data-directed)	Uses known SOI pilots or training signals to develop weights Requires known SOI pilot, estimation of FOA and TOA for sync	Highest SINR; strongest excision capability FOA and TOA provided Higher loading limits	Requires knowledge or provision of pilot Requires allocation of channel resources to pilot
Structure based (blind data-directed)	Uses known/induced SOI <u>structure</u> to develop weights Requires known SOI structure	Performs under strong interference Capture without FOA/TOA Higher loading limits	Sensitive to SOI model error Potential capacity loss due to imposition of structure

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Comparison of SOI Capture Results, Extreme Environment (16.51 dB Ideal Max SINR)

Parametric Channel-Directed

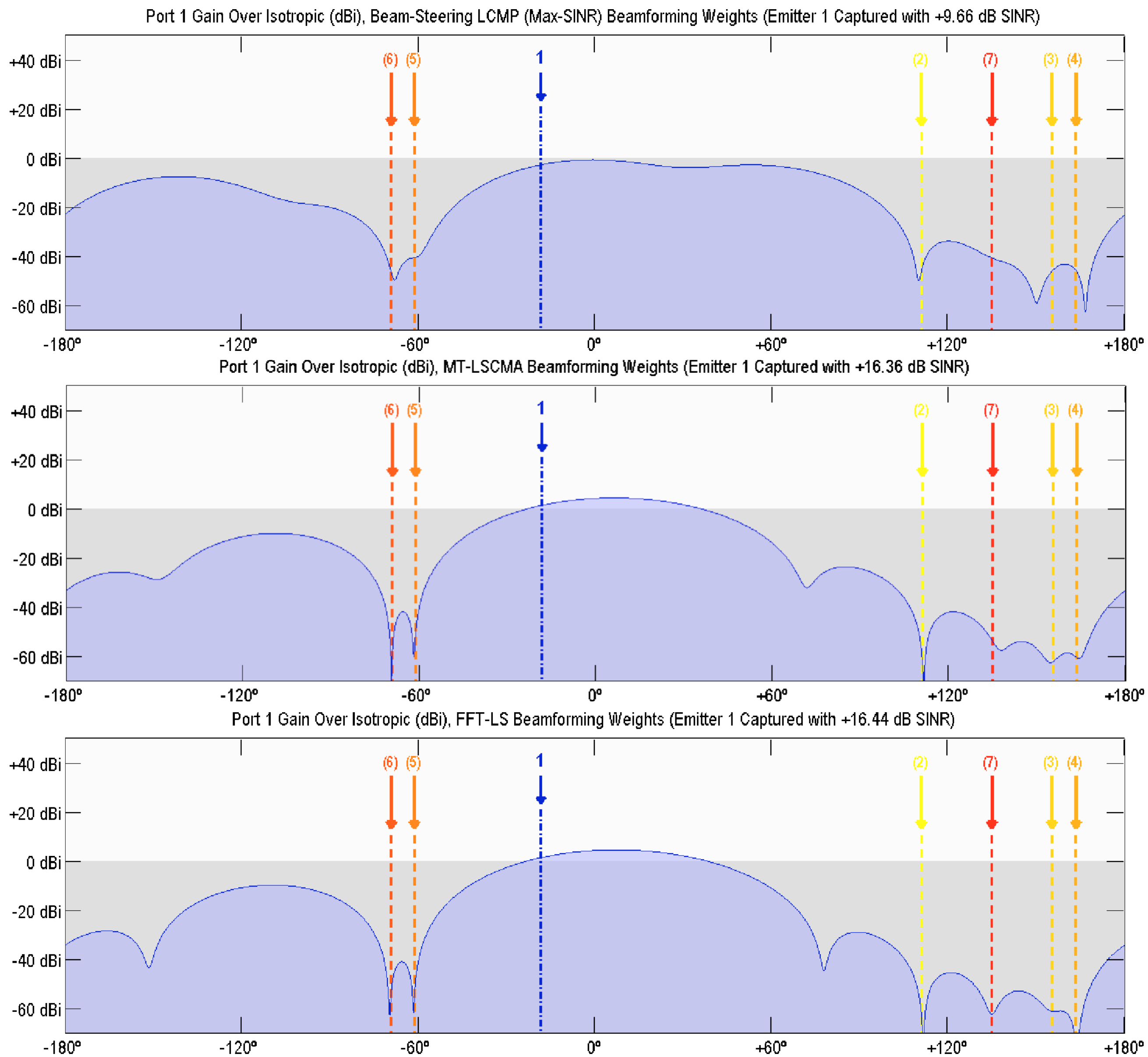
- Linearly-constrained power minimization, known DOA
- 6.85 dB misadjustment

Blind Data-Directed

- Static least-squares CMA
- 0.15 dB misadjustment

Nonblind Data-Directed

- FFT least-squares algorithm
- 0.07 dB misadjustment



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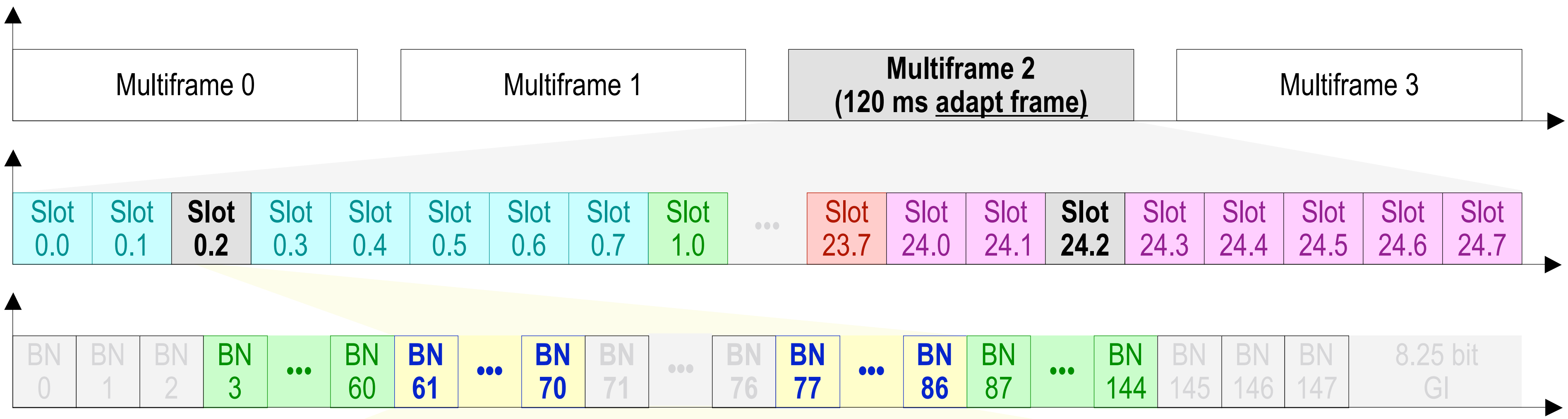
Example Data-Directed Methods

	Example PHY	Example Algorithm
• Known components		
– Pilots, preamble, midambles	GSM, UMTS, 802.11 DSS PHY	FFT least-squares (FFT-LS)
– OFDM training signals	802.11 OFDM PHY's	FFT-LS
• Limited time/frequency support		
– Limited time support	GSM, Bluetooth	Time-gated dominant mode prediction (TG-DMP)
– Limited frequency support	GSM, Bluetooth	Frequency-gated DMP (FG-DMP)
– Known DSSS code	802.11, UMTS	Code-gated DMP (CG-DMP)
• Self-coherence properties		
– BPSK, ASK, OOK, MSK, CSK	802.11, Zigbee	Conjugate self-coherence restoral (C-SCORE)
– PAM PHY	GSM/EDGE	Auto-SCORE (A-SCORE)
– OFDM cyclic prefix	802.11, 802.16, LTE DL	Auto-SCORE (A-SCORE)
• Modulus properties		
– Constant waveform modulus	GSM, Bluetooth	Least-squared CMA (LSCMA)
– Constant symbol modulus	EDGE, 802.11 DSS, CCK, OFDM SIGNAL	LSCMA (FSE structure)
– Multiple symbol moduli	802.11 OFDM, 802.16 DL	COMA, LSMMA
– Known symbol constellation	802.11, 802.16 OFDM	Decision direction/feedback (DDA/DFA)

Example Nonblind Data-Directed Method: FFT Least-Squares

- Applicable to applications in which the signal of interest contains a known or estimable pilot with an unknown delay or frequency offset
  - GSM training sequence code (TSC) (8 possible)
  - Pilot modulated bits on UMTS UL-DPCCH (4 possible in uncompressed slot formats)
  - 802.11 DSS and CCK preamble (two possible preambles — more if nonstandard initial state used)
  - 802.11 OFDM long training sequence (L-LTF); 802.11n HT-LTF
  - 802.11 OFDM short training sequence (L-STF), HT-STF, pilot subcarriers, low dispersion channels
- Straightforward extension of least-squares method for capture of signals with unknown FOA or TOA
  - Mechanized at low cost using QRD and FFT algorithms
  - Coreware available for implementation in FPGA (e.g., Xilinx FFT and Accelware cores)
- Drawbacks:
  - Requires knowledge/search over pilot signal
  - Only optimizes SINR over the pilot interval or channel
    - » Limits applicability to many commercial waveforms
    - » Vulnerable to intelligent jamming measures if not added correctly

Example: GSM Training Sequence Code (TSC)



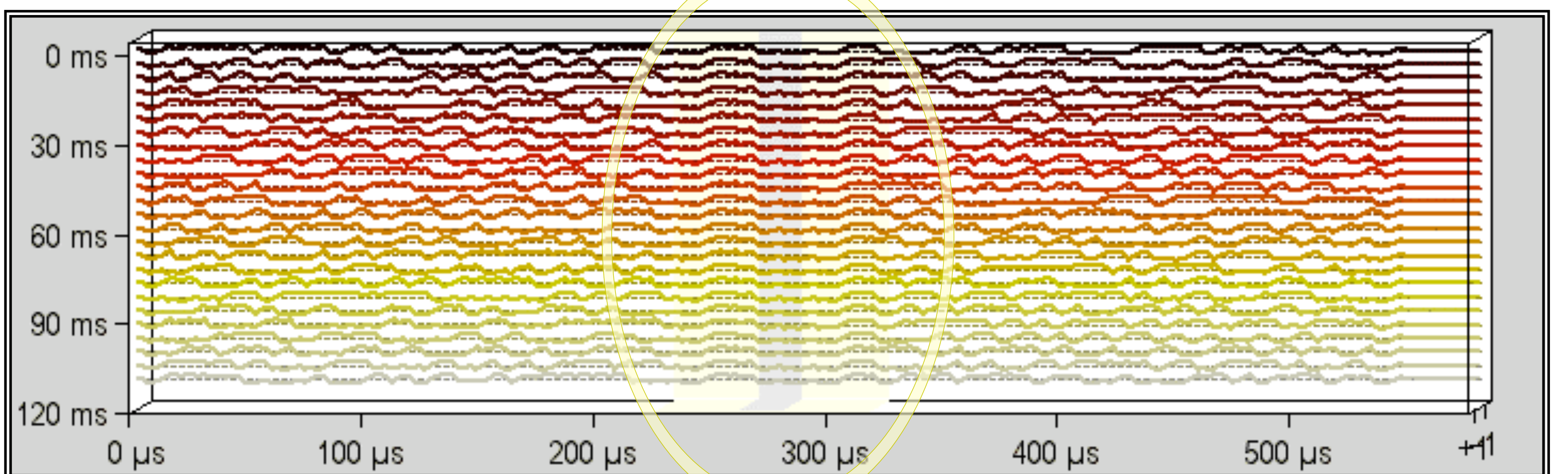
TSC	Midamble Bit (GSM 5.02, A = BN61, Z = BN86)																									
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
0	0	0	1	0	0	1	0	1	1	1	0	0	0	0	1	0	0	0	1	0	0	1	0	1	1	1
1	0	0	1	0	1	1	0	1	1	1	0	1	1	1	1	0	0	0	1	0	1	1	0	1	1	1
2	0	1	0	0	0	0	1	1	1	0	1	1	1	0	1	0	0	1	0	0	0	0	1	1	1	0
3	0	1	0	0	0	1	1	1	1	0	1	1	0	1	0	0	0	1	0	0	0	1	1	1	1	0
4	0	0	0	1	1	0	1	0	1	1	1	0	0	1	0	0	0	0	0	1	1	0	1	0	1	1
5	0	1	0	0	1	1	1	0	1	0	1	1	0	0	0	0	0	1	0	0	1	1	1	0	1	0
6	1	0	1	0	0	1	1	1	1	1	0	1	1	0	0	0	1	0	1	0	0	1	1	1	1	1
7	1	1	1	0	1	1	1	1	0	0	0	1	0	0	1	0	1	1	1	0	1	1	1	1	0	0

Cyclic structure

Example: GSM Training Sequence Code (TSC)

Encode data bits → Insert TSC, tail bits → Map to to DBPSK → Gaussian filter → Frequency modulate

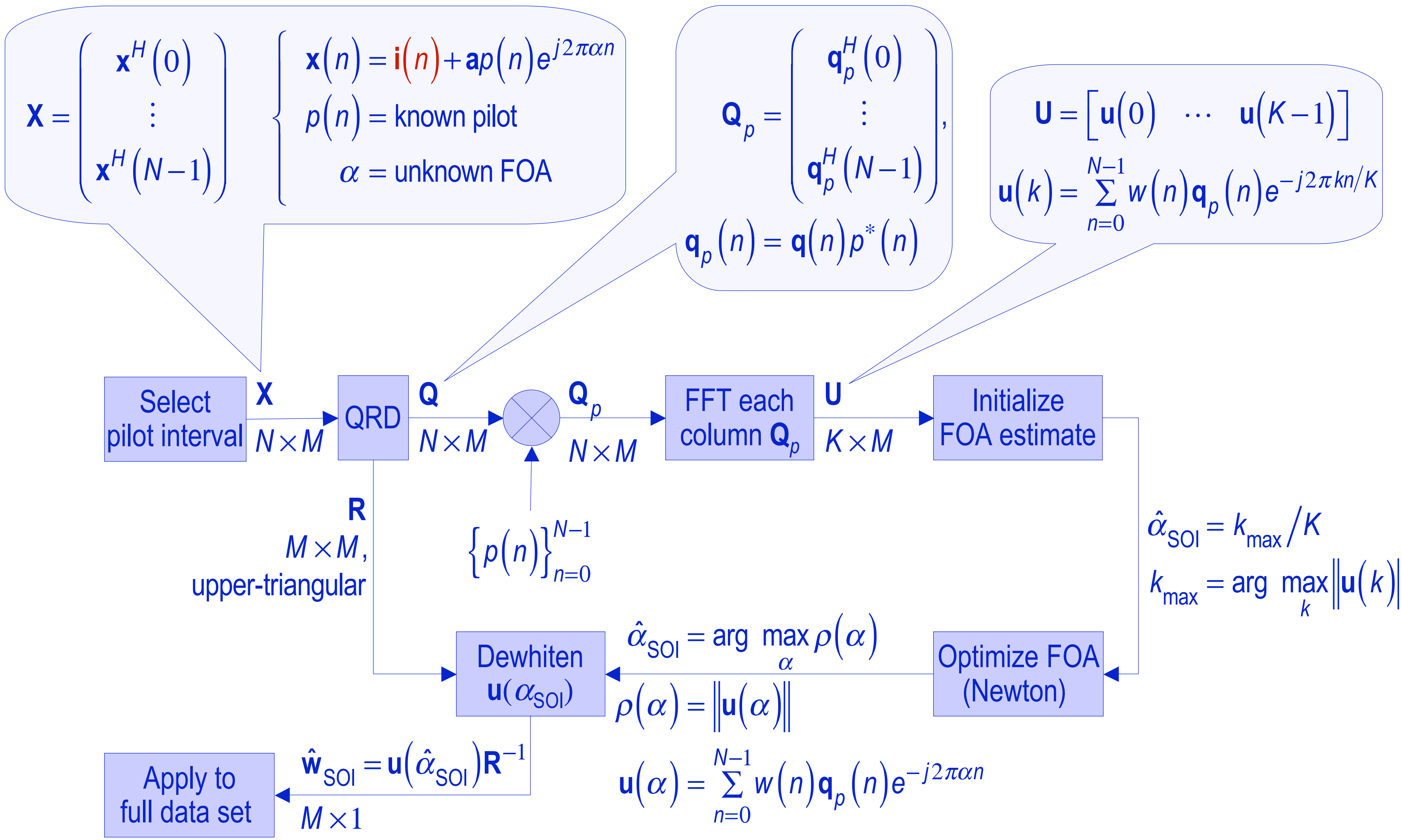
Frame-Rastered Transmit Data
(constant frame phase and carrier offset removed)



Exploitable Pilot

- **Known complex amplitude over TSC time segment**
- **Cyclic structure over first & last 10 TSC symbols**
- **Unknown (estimable) interframe phase & carrier offset**

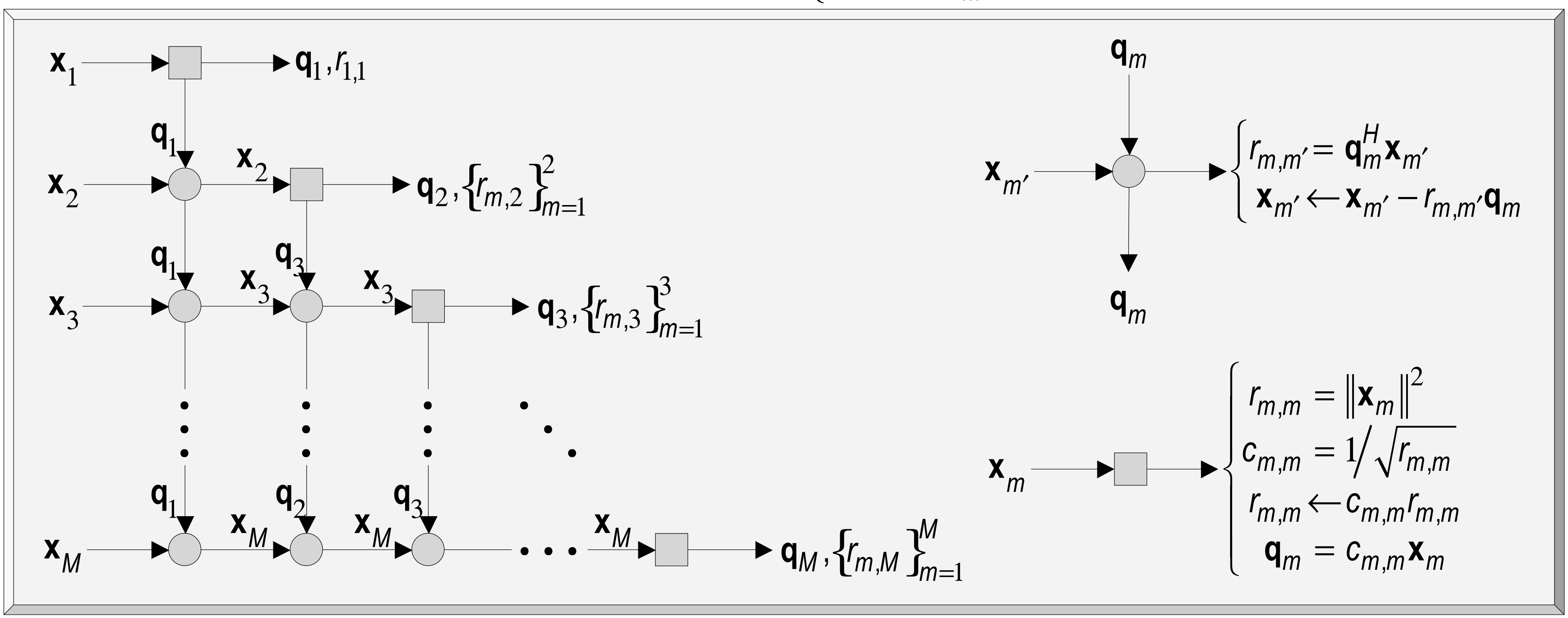
FFT-LS Algorithm



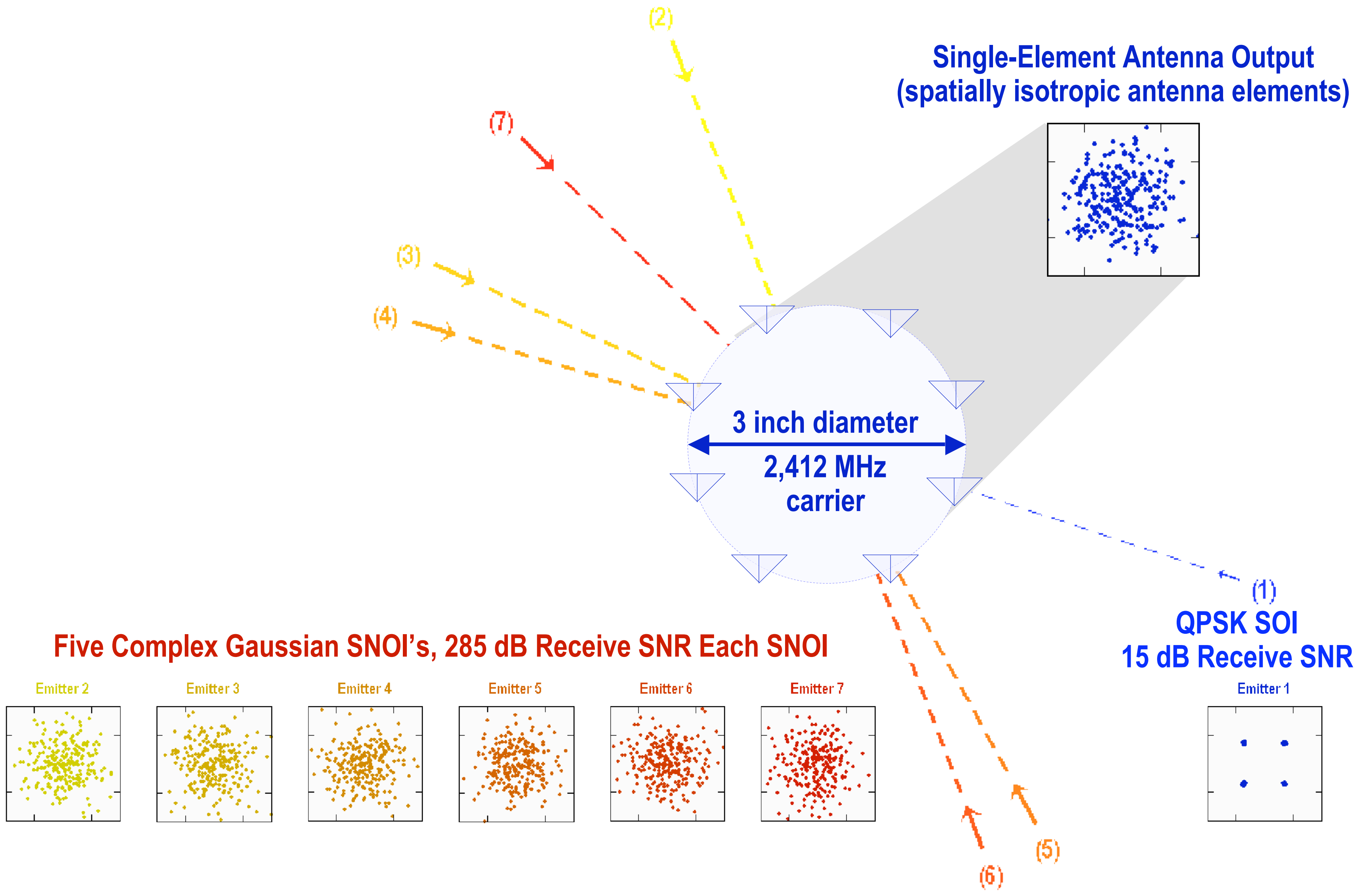
Example QRD: Modified Gram-Schmidt Orthogonalization

$$\underset{N\times M}{\mathbf{X} = \begin{bmatrix}\mathbf{x}_1 & \cdots & \mathbf{x}_M\end{bmatrix}} \longrightarrow \boxed{\text{QRD}} \longrightarrow \{\mathbf{Q},\mathbf{R}\}$$

$$\mathbf{X} = \mathbf{QR} \quad \left\{\begin{aligned} \mathbf{R} &= \begin{pmatrix} r_{1,1} & \cdots & r_{1,M} \\ & \ddots & \vdots \\ 0 & & r_{M,M}\end{pmatrix}, \quad M\times M, \text{ upper-triangular} \\ &= \text{chol}\{\mathbf{X}^H\mathbf{X}\} \\ \mathbf{Q} &= \begin{bmatrix}\mathbf{q}_1 & \cdots & \mathbf{q}_M\end{bmatrix}, \quad N\times M,\ N\geq M \\ \mathbf{Q}^H\mathbf{Q} &= \mathbf{I}_M \end{aligned}\right.$$



Demonstration for Extreme Excision Example



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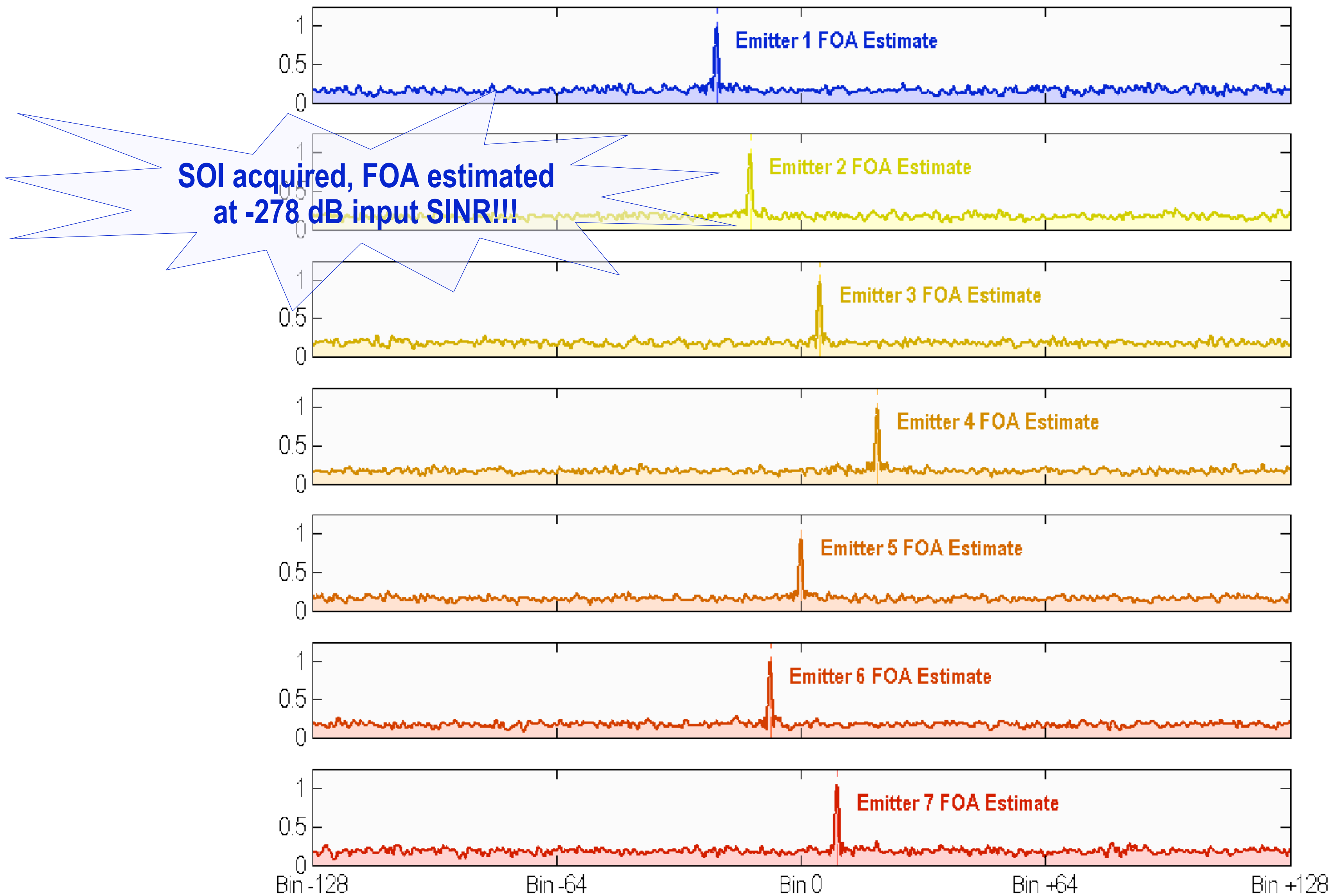
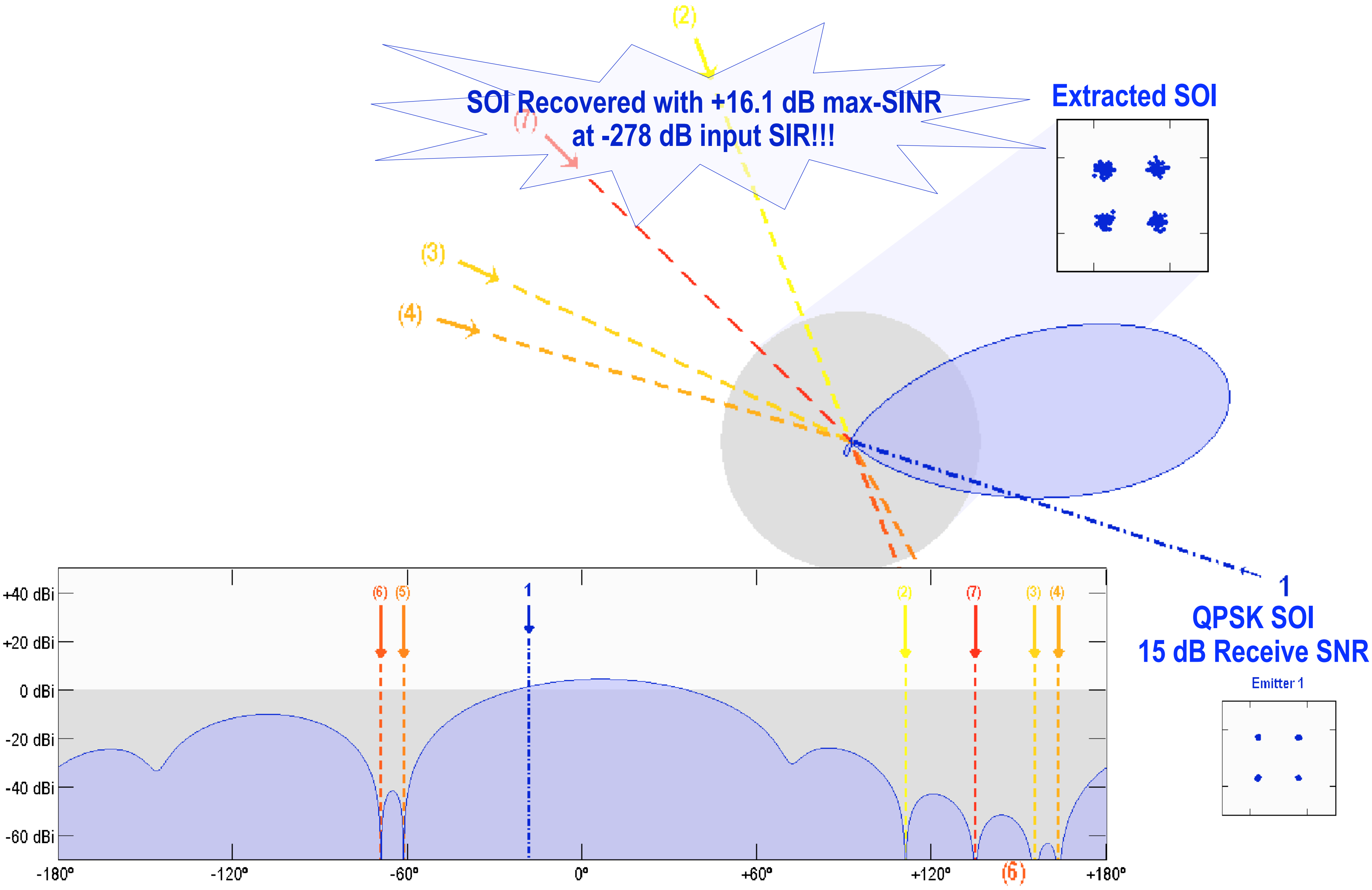
FFT-LS FOA Spectra Each Emitter, TBP = 256



FFT-LS SOI Extraction Performance, 256-Symbol TBP



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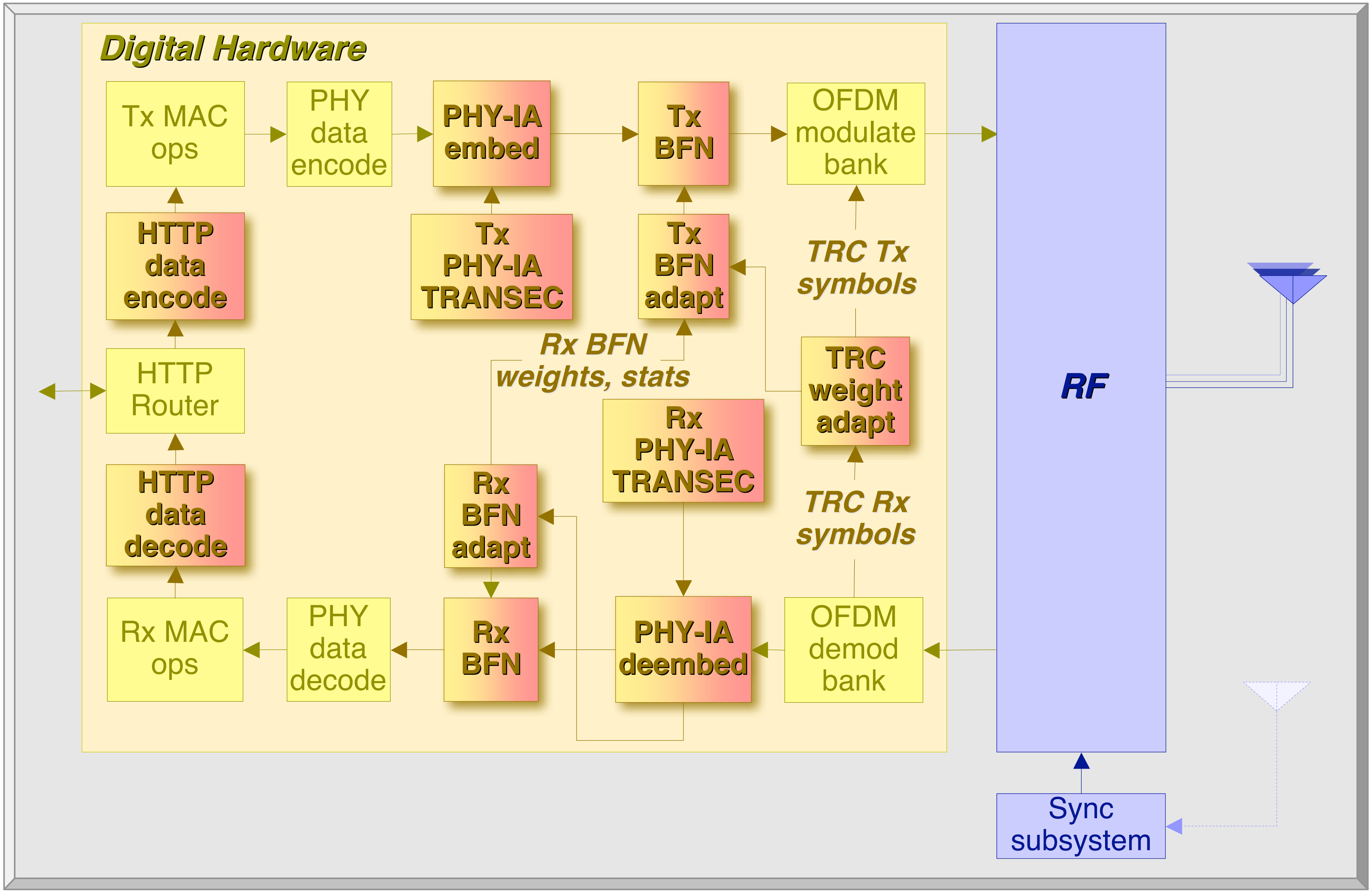
Implementation in Fully Adaptive MIMO Networking Transceiver*



US 7,248,841 and patents pending

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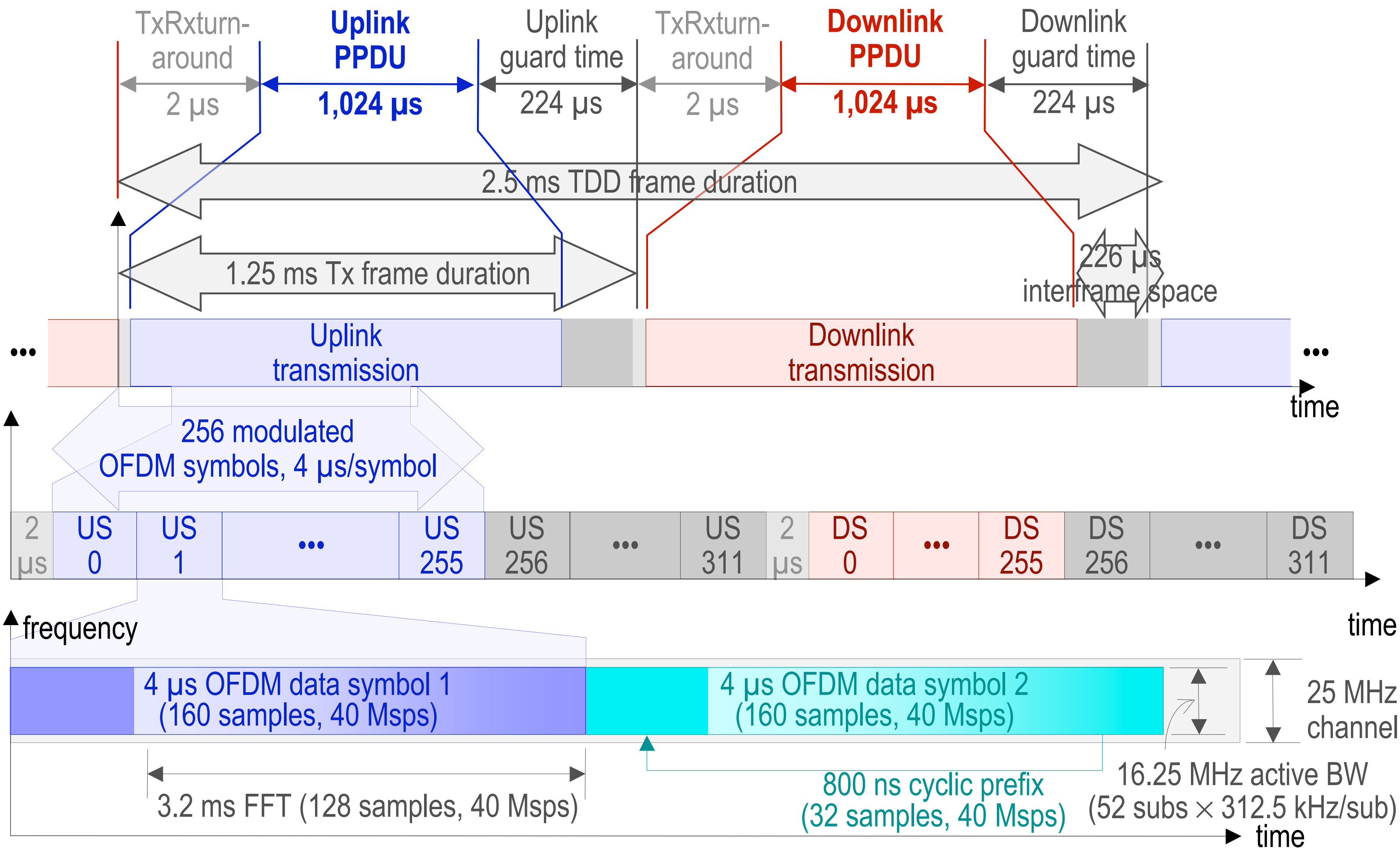
802.11 Compatible PHY Time Framing



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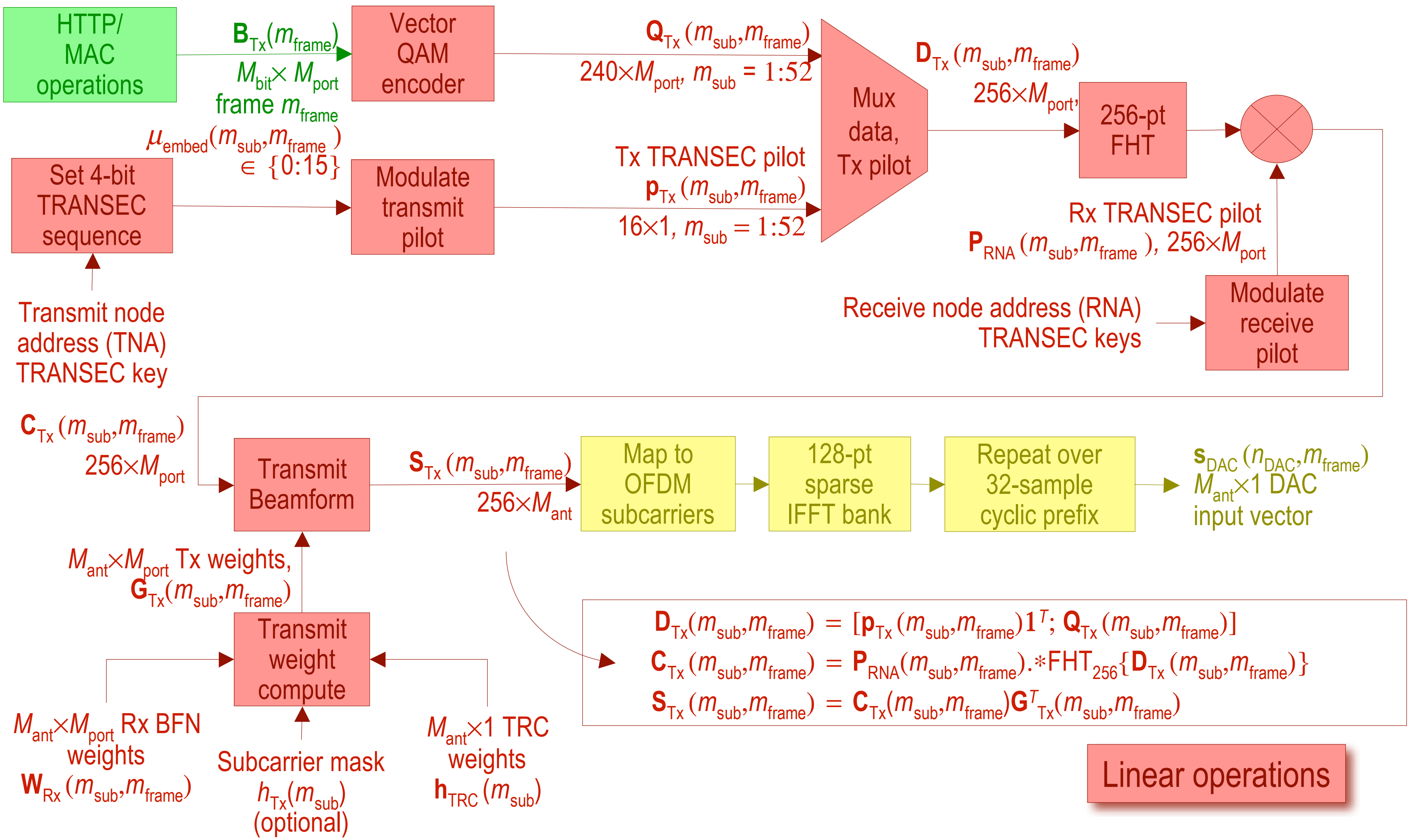
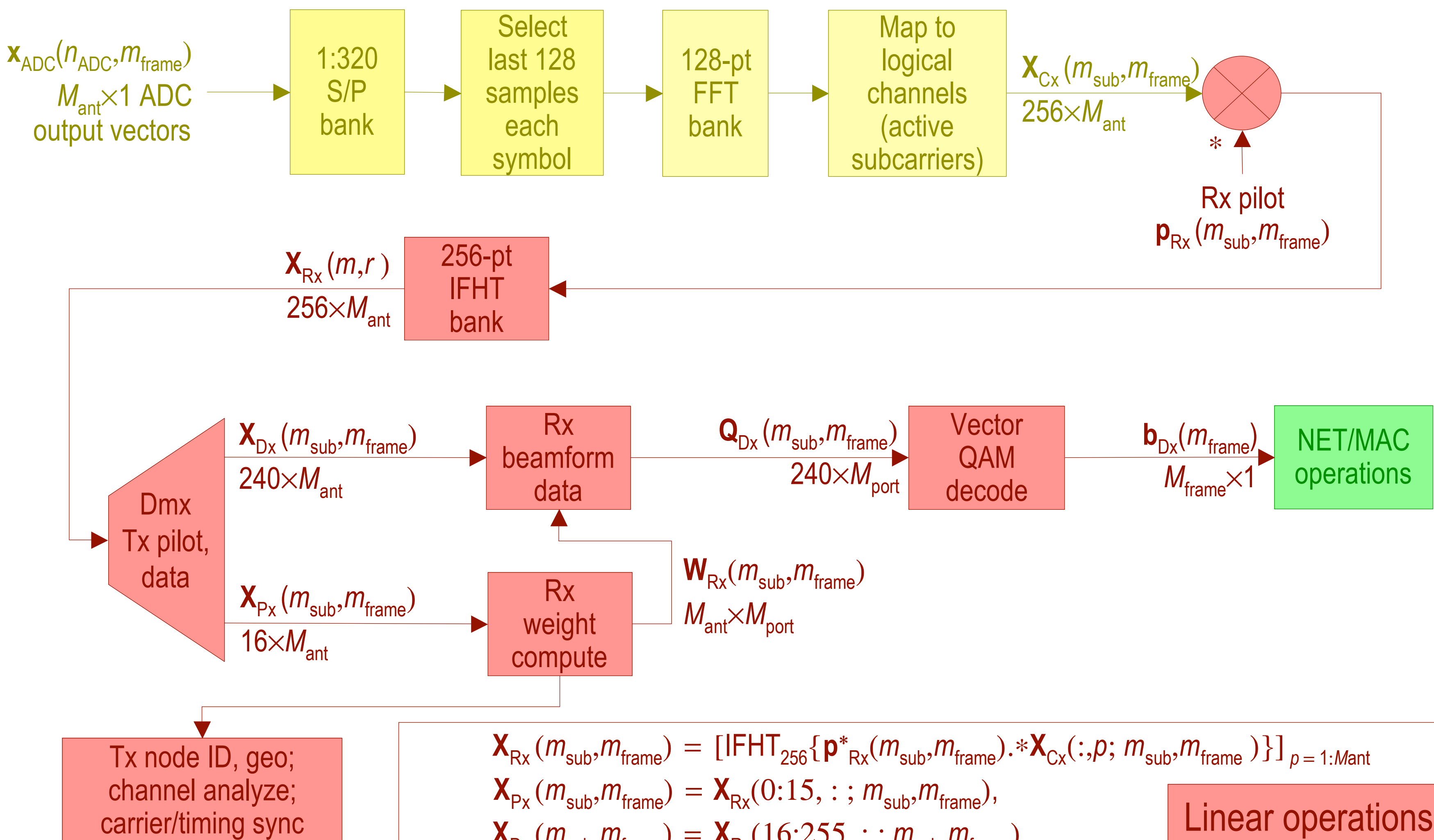
Multiport PHY Transmit Processing



$$\mathbf{D}_{\mathrm{Tx}}(m_{\mathrm{sub}}, m_{\mathrm{frame}}) = [\mathbf{p}_{\mathrm{Tx}}(m_{\mathrm{sub}}, m_{\mathrm{frame}})1^T; \mathbf{Q}_{\mathrm{Tx}}(m_{\mathrm{sub}}, m_{\mathrm{frame}})]$$
$$\mathbf{C}_{\mathrm{Tx}}(m_{\mathrm{sub}}, m_{\mathrm{frame}}) = \mathbf{P}_{\mathrm{RNA}}(m_{\mathrm{sub}}, m_{\mathrm{frame}}).{*}\mathrm{FHT}_{256}\{\mathbf{D}_{\mathrm{Tx}}(m_{\mathrm{sub}}, m_{\mathrm{frame}})\}$$
$$\mathbf{S}_{\mathrm{Tx}}(m_{\mathrm{sub}}, m_{\mathrm{frame}}) = \mathbf{C}_{\mathrm{Tx}}(m_{\mathrm{sub}}, m_{\mathrm{frame}})\mathbf{G}^T_{\mathrm{Tx}}(m_{\mathrm{sub}}, m_{\mathrm{frame}})$$

Multiport PHY Receive Processing



$$\mathbf{X}_{Rx}(m_{sub},m_{frame}) = [\mathrm{IFHT}_{256}\{\mathbf{p}^*_{Rx}(m_{sub},m_{frame}).*\mathbf{X}_{Cx}(:,p;\, m_{sub},m_{frame})\}]_{p=1:Mant}$$

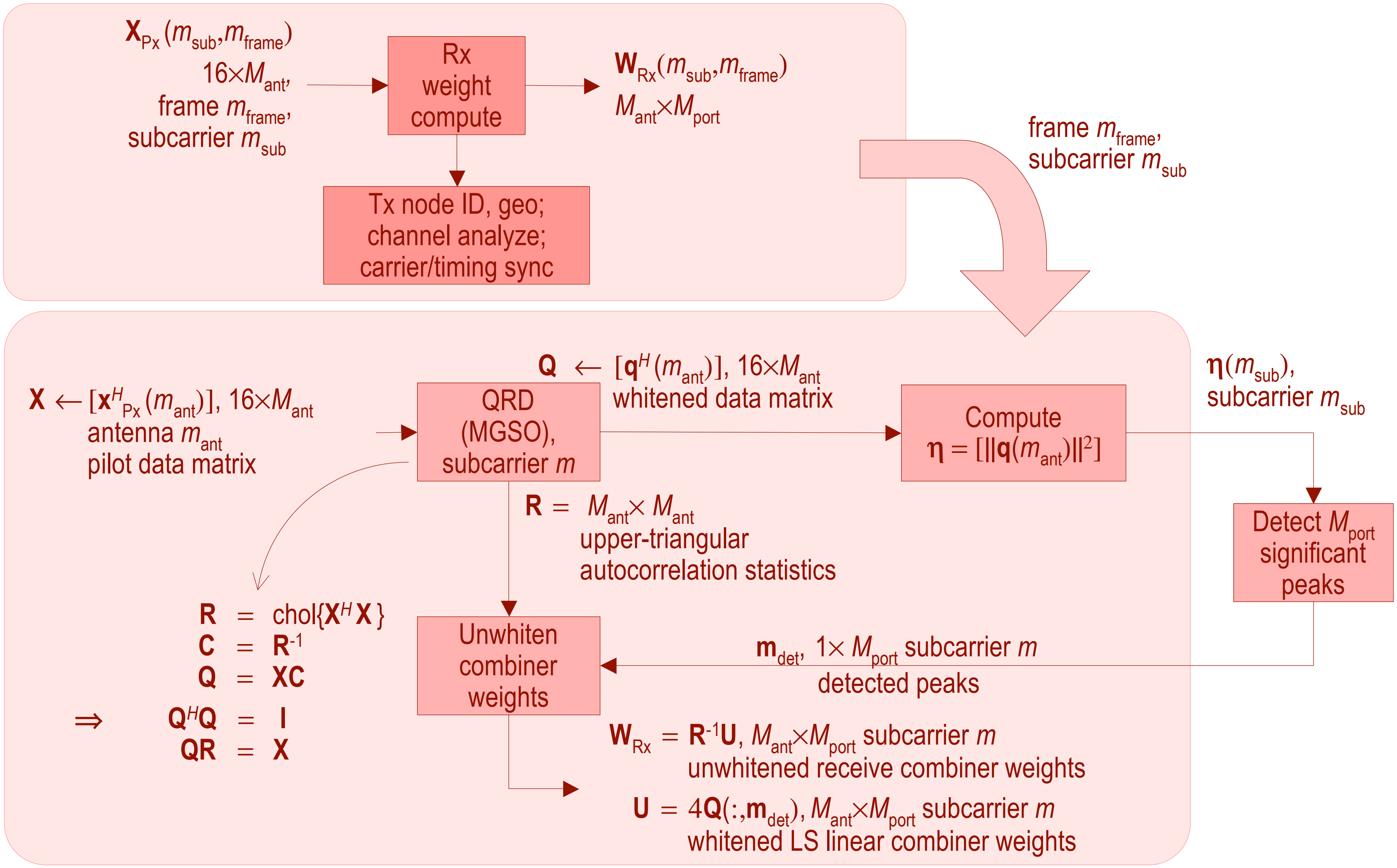
$$\mathbf{X}_{Px}(m_{sub},m_{frame}) = \mathbf{X}_{Rx}(0{:}15,:\,;\, m_{sub},m_{frame}),$$

$$\mathbf{X}_{Dx}(m_{sub},m_{frame}) = \mathbf{X}_{Rx}(16{:}255,:\,;\, m_{sub},m_{frame}),$$

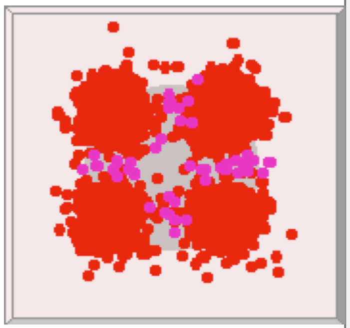
$$\mathbf{Q}_{Dx}(m_{sub},m_{frame}) = \mathbf{X}_{Dx}(m_{sub},m_{frame})\,\mathbf{W}_{Rx}(m_{sub},m_{frame})$$

Linear operations

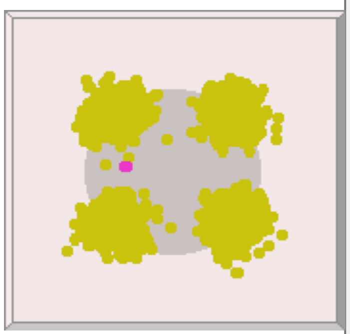
Receive Adaptation Algorithm



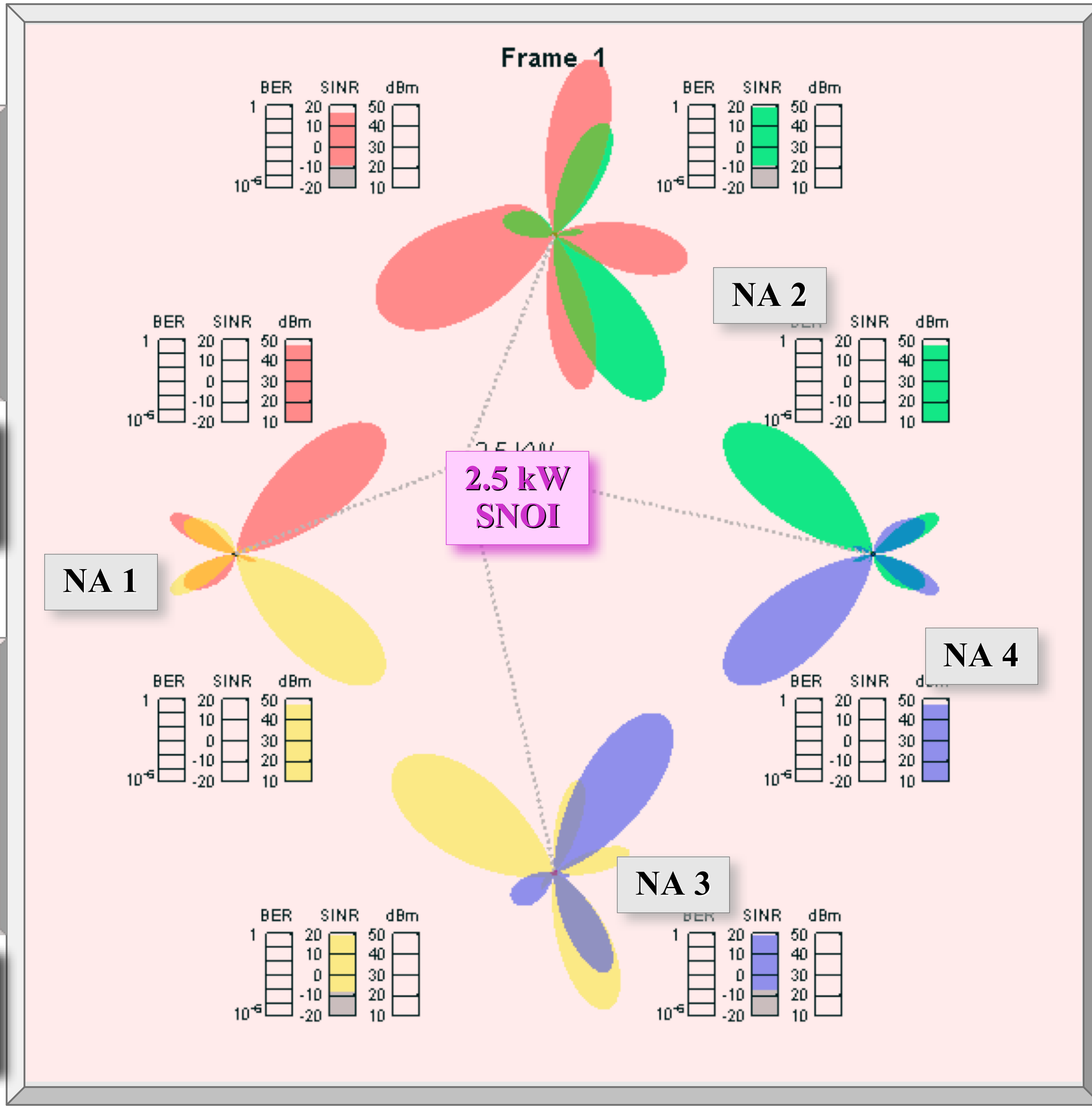
Example Network Simulation

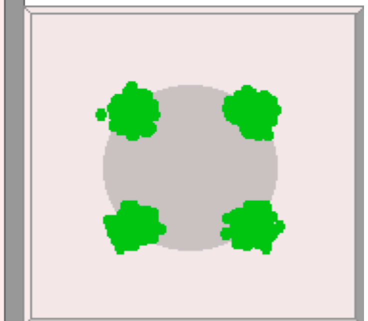


TNA: 1
RNA: 2
BER: 0.1%

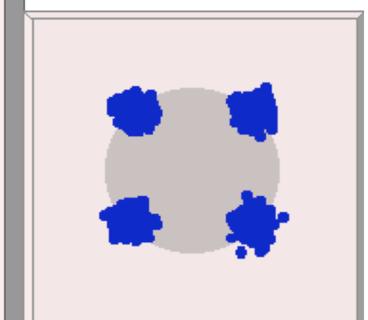


TNA: 1
RNA: 3
BER: 0.005%





TNA: 4
RNA: 2
BER: No errors



TNA: 4
RNA: 3
BER: No errors

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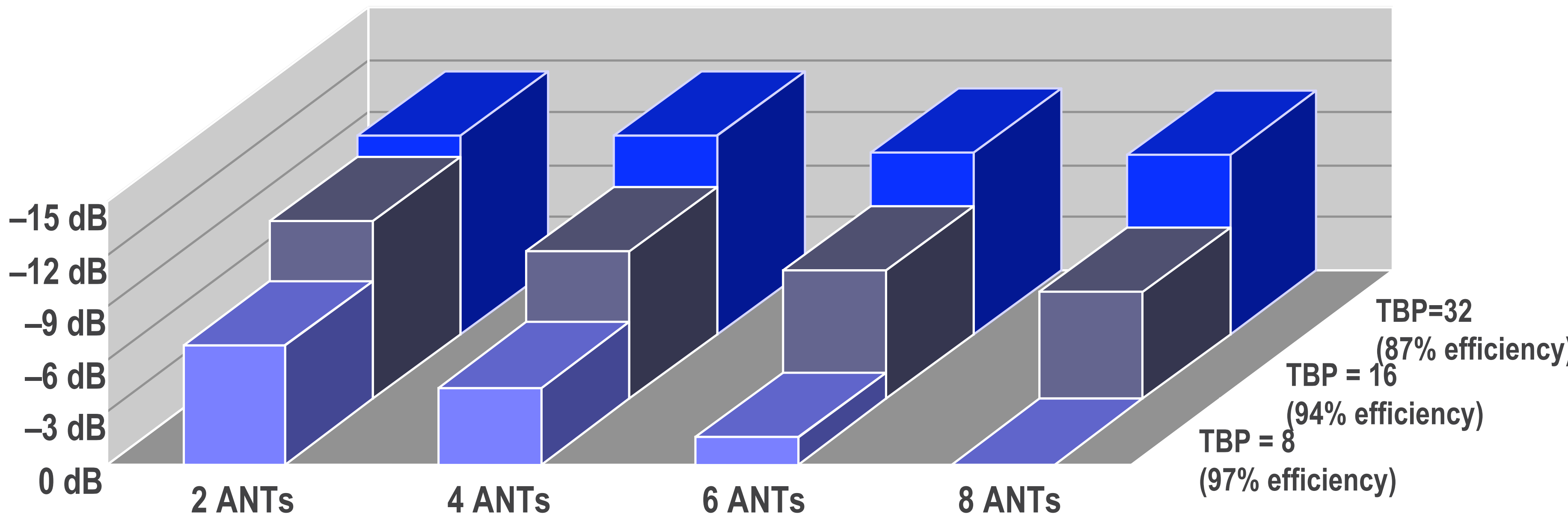
Detect Performance, 1% Miss-Rate, FAR (4 Misses, False Alarms/Second)



- Detects intended transmit nodes at negative receive SINR's
  - –6 dB maximum attainable SINR for TBP of 16, in single 1.25 ms frame
  - –10 dB max SINR at TBP of 32
  - Equivalent to -9 dB to -19 dB receive SINR (LPD)
- Very low adaptation overhead (87%-98% link efficiency)
- Easily scalable in antenna or TBP dimensions

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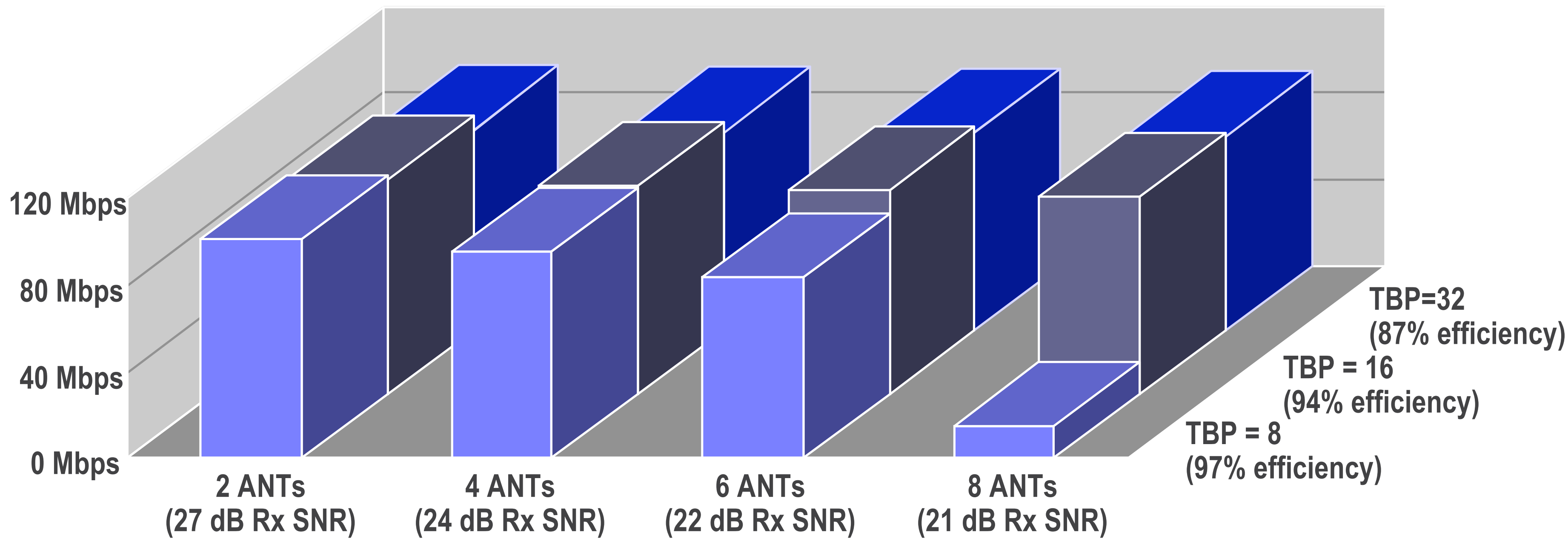
Example Throughput per Port (Mbps/Port), 30 dB Max Attainable SINR



- Reflects tradeoff between adapt overhead & performance
  - Adapt TBP sets maximum efficiency
  - Adapt performance sets actual SINR & Capacity

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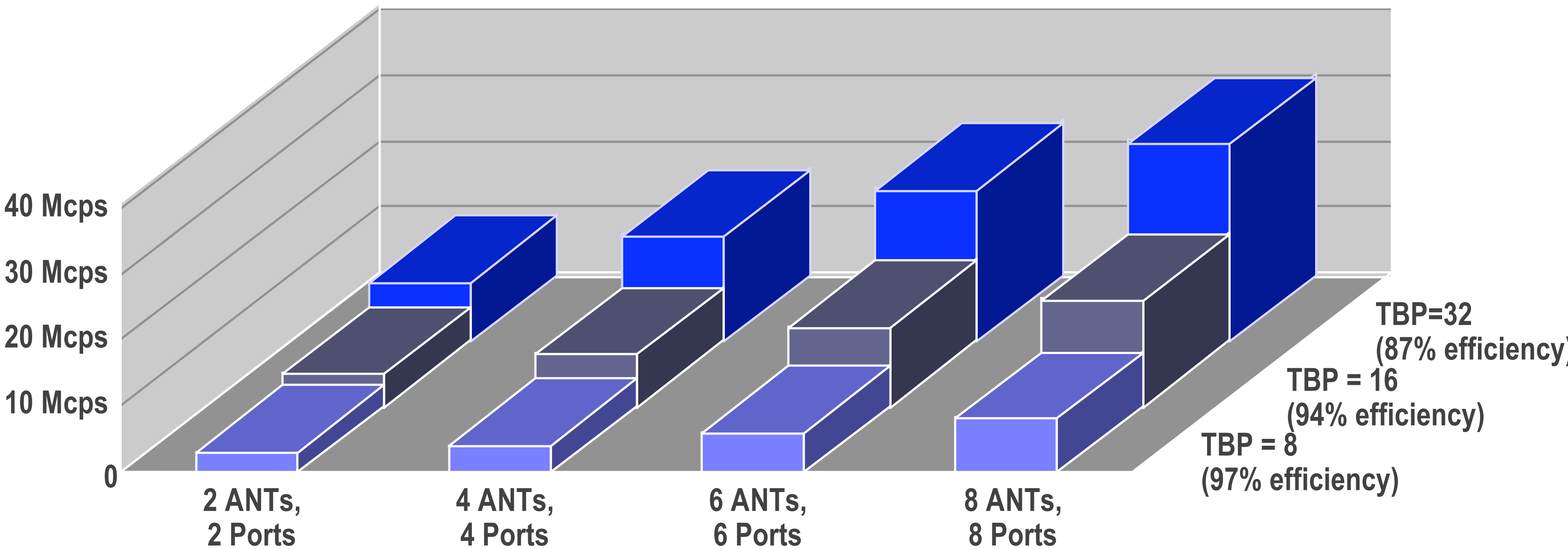
Adaptation Algorithm Complexity (Expected DSP Operations), Mcps/Port



- All TBP's achievable in SW at reasonable operations per port
  - Fit within low-cost C6701 computational cycles
  - 2/3 derating added to account for memory transfer issues
- All TBP = 16 ports achievable on a single DSP, 6 or fewer ANT's and ports (≤ 120 Mcps total operations)

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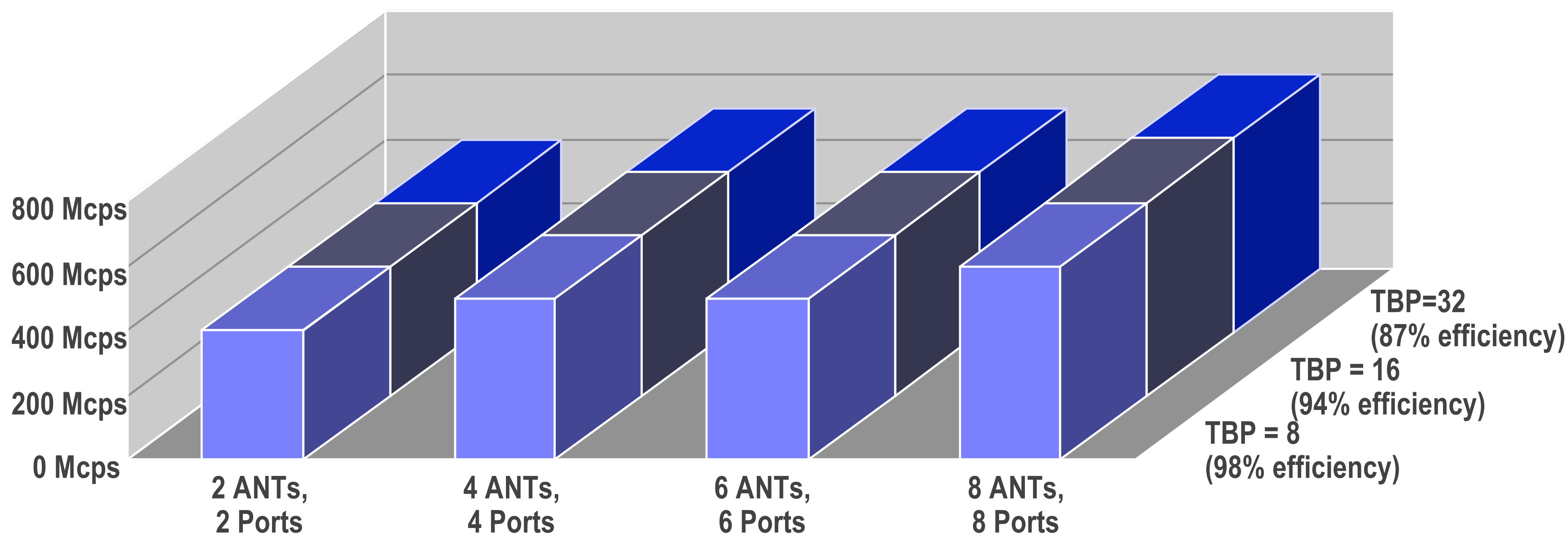
Transceiver Complexity (Expected Coreware Operations), Mcps/Port



- Performance nearly invariant to number of antennas!
  - Reflects linear complexity growth with number of ANT's
  - Operations dominated by OFDM modem!

Implementation Considerations

- Theoretical results will be limited in practice by a host of realistic system issues:
  - System and environment noise
  - Receiver bandwidth
  - Channel/array modeling error
  - Platform dynamics
  - Environment dynamics
  - Receiver precision
    - » LNA nonlinearity
    - » LO phase noise, IQ imbalance
    - » Cross-sensor filter mismatches (BPF, LNA harmonic filter, antialiasing LPF's, ADC hold time)
    - » ADC precision
  - Adaptation algorithm complexity
    - » Steepest descent versus rapidly converging methods
    - » Power-domain (matrix inversion) versus voltage domain (QRD)
  - Time-bandwidth product constraints (e.g., SOI/pilot duration, interarrival times)
- All of these issues will limit interference excision performance
  - Number of interferers that can be excised
  - Depth of nulls produced
- Results can be highly dependent on excision structures and methods chosen